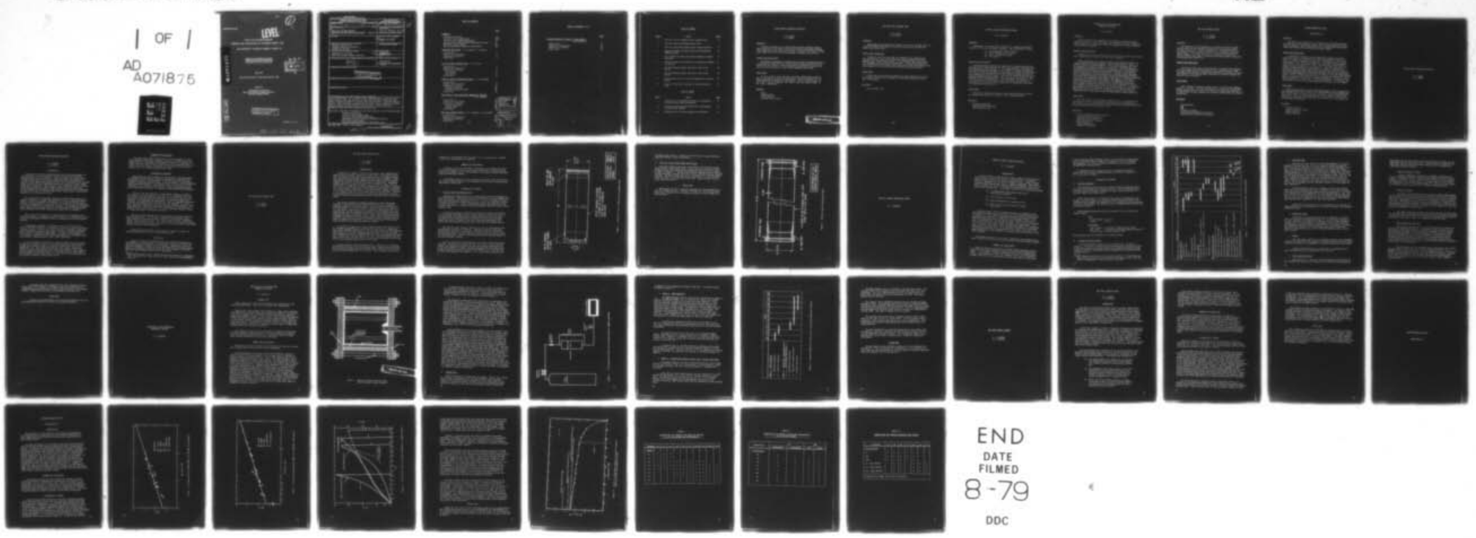
AD-A071 875 HERCULES INC CUMBERLAND MD ALLEGANY BALLISTICS LAB F/G 21/8.2
NAVAL SEA SYSTEMS COMMAND RESEARCH AND EXPLORATORY DEVELOPMENT --ETC(U)
MAR 79 N00024-79-C-5314

UNCLASSIFIED NL



AO4104-101-07-001

LEVEL II

NAVAL SEA SYSTEMS COMMAND

RESEARCH AND EXPLORATORY DEVELOPMENT REPORT—1978

ABL QUARTERLY TECHNICAL SUMMARY REPORT 86

AD A071875

HERCULES AEROSPACE DIVISION
HERCULES INCORPORATED
ALLEGANY BALLISTICS LABORATORY
CUMBERLAND, MARYLAND

March 1979

Work Period: November 10, 1978 through January 30, 1979

Prepared for

DEPARTMENT OF THE NAVY
NAVAL SEA SYSTEMS COMMAND (SEA-0331)
CONTRACT N00024-79-C-5314

Copy No. ________

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER (9) Quarterly technical	2. GOVT ACCESSION NO. summary	3. RECIPIENT'S CATALOG NUMBER rept. 10 Nov 78-30 Jan 79.
4. TITLE (and Subtitle) (6) NAVAL SEA SYSTEMS COMMAND RESEARCH AND EXPLORATORY DEVELOPMENT - 1978. (U)		5. TYPE OF REPORT & PERIOD COVERED Quarterly - Nov. 10, 1978-Jan. 30, 1979
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s)		8. CONTRACT OR GRANT NUMBER(s) (15) N00024-79-C-5314
9. PERFORMING ORGANIZATION NAME AND ADDRESS Hercules Incorporated Allegany Ballistics Laboratory Cumberland, Maryland		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Department of the Navy Naval Sea Systems Command (SEA-0331)		12. REPORT DATE (11) March 1979
		13. NUMBER OF PAGES 35
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) (12) 47 p.		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

This document has been approved for public release and sale; its distribution is unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Plume transmissivity, strip laminate case, XLDB propellants, NEPE propellants, bonding agents, HMX, RDX, Polymer coatings, Nitrate Ester Plasticizer polyethers, propellant mechanical failure, ballistic modifiers, smokeless XLDB propellant, IR/UV emissions, crosslink density (XLD), Strain Evaluation Cylinders (SEC's), uniaxial and multi-axial strain endurance, failure prediction.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report describes the progress in the first quarter on the following tasks:

Signature Evaluation,
Low Cost Strip Laminate Case,
Vertical Launch Controllable Motor,
Prediction of XLDB Propellant Mechanical Failure,
HMX (RDX) Bonding Agents,
Polymer Morphology Studies of XLDB Binder.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

401 824

79 06 15 010

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont.)

LIST OF FIGURES

LIST OF TABLES

ROCKET MOTOR SIGNATURE EVALUATION

T. E. Durney
A. G. Moore

Objective

Provide an insight to the relationship between signature measurements conducted in an outdoor static test facility and results obtained from flight and flight simulation testing in parallel tri-service testing. Scale model motors will also be evaluated to provide scale factors.

Results and Conclusions

Preliminary experiments to develop motor plume UV energy with motors of opportunity showed that far greater detector sensitivity will be required than that tested. Work has started on adapting the various full size tactical test motors to the slanted signature test stand.

Future Work

A total of forty scale and full size motor firing tests producing data on the photopic and IR transmissivity, photopic reflectivity, and IR/UV emissions is planned for the program. Full size motors include Mk 53 Mod 3 and Mk 78 Shrikes, Mk 71 Mod 1 Zuni, Mk 4 Mod 10 FFAR, and Mk 17 Mod 5 Sidewinders.

Keywords

Plume
Transmissivity
IR/UV emissions
Tactical solid rockets

PRECEDING PAGE BLANK

LOW COST STRIP LAMINATE CASE

D. W. Fertig
J. M. Viles

Objective

Demonstrate the feasibility of using a steel strip laminate case for a typical NAVSEA rocket motor and provide two cases for the Vertical Launch Controllable Motor.

Results and Conclusions

A 3000 psi proof test and 3500 psi hydroburst test demonstrated that aluminum end rings and closures are viable approaches for large diameter steel strip laminate cases. The hydroburst test showed excellent agreement with the structural analysis. A preliminary design of a case utilizing the Mk 56 rocket motor steel end closure configuration has been prepared for the Vertical Launch Propellant Evaluation Motor.

Future Work

A case will be tested with aluminum end rings designed for a 3750 psi chamber pressure and the design of a case with steel end closures will be completed.

Key Words

Strip laminate case

VERTICAL LAUNCH CONTROLLABLE MOTOR

E. D. Casseday

Objective

Demonstrate the technologies required for a common controllable booster in full-size test-weight hardware. The technologies include:

(1) A minimum-smoke XLDB propellant
(2) Strip laminate low cost case
(3) Thrust termination system
(4) TVC system

Results and Conclusions

Detailed program planning was completed for incorporating results from last year's propellant and low cost strip laminate case tasks into the demonstration motor design. It is planned to design, manufacture and test two demonstration motors. The cases to be used for these motors will consist of strip laminate tubes with adhesive bonded joint Mk 56 case forward domes and aft rings. They will be insulated and cast with smokeless XLDB propellant grains. The first motor test will be a full duration firing to demonstrate (1) strip laminate case integrity, and (2) full-scale motor performance. The second motor firing will be terminated at two-thirds of the burning time to demonstrate propellant extinguishment characteristics.

Future Work

Finalize the demonstration motor design and manufacture and test two demonstration motors as outlined in the program schedule.

Key Words

Ballistic modifiers
Smokeless XLDB propellant
Strip laminate case

PREDICTION OF XLDB PROPELLANT MECHANICAL FAILURE

G. E. Herriott

Objective

The objective of the program is to establish correlations among mechanical property tests and rocket motor behavior such that propellant grain failure in a rocket motor under low temperature storage conditions can be reliably predicted.

Results and Conclusions

During the past report period, data from the FY-78 study were reviewed and a program plan for the FY-79 effort was formulated.

Three propellants with various stress-strain behaviors typical of current state-of-the-art propellants will be step-cooled to failure in strain evaluation cylinders (SEC's). This failure behavior will then be compared to mechanical property test results. The time dependent strain endurance capabilities of the propellants will be characterized in particular since long term strain induced failure is the primary mode of failure for the step-cooled SEC's. Uniaxial strain endurance will be determined at various temperatures and conditioning histories. To provide strain endurance data under conditions more closely simulating those in a low temperature conditioned rocket motor, a multi-axial strain endurance test will be developed. The feasibility of such a test has been demonstrated under exploratory IR&D work by Hercules. Other uniaxial mechanical properties will also be obtained to provide the necessary characterization data for the propellants. It is expected that correlation of the uniaxial and multi-axial test data with the SEC failure data will result in a technique to predict the failure conditions for a rocket motor under low temperature storage conditions.

Future Work

The multi-axial strain endurance apparatus will be fabricated and checked out. After the fabrication and checkout of this apparatus is well under way, the propellants for further mechanical property characterization and analysis will be manufactured.

Key Words

Strain Evaluation Cylinders (SEC's)
Propellant Mechanical Failure
Uniaxial strain endurance
Multi-axial strain endurance
XLDB propellants
Failure prediction
Mechanical Properties

HMX (RDX) BONDING AGENTS

M. T. Donohue
J. R. Gallion

Objective

The objective of this program is to identify the effect of RDX bonding agents on the mechanical properties of high solids content energetic propellants. These propellants will be manufactured with the advanced "tough propellant" nitrate ester plasticizer polyether (NEPE) binders. A second objective is to improve the previously developed HMX bonding agent to withstand high shear mixing encountered during propellant manufacture.

Results and Conclusions

Laboratory efforts have been initiated to determine the effectiveness of the HDI-cured glycerol-ethylene glycol bonding agent on RDX in a NEPE binder system. Attempts are being made to increase the cross-link density of the bonding agents developed in the FY-77 program for improved shear resistance.

Future Work

The screening of potential modifications to the selected bonding agent will continue. The best systems will be tested for effectiveness on HMX and RDX and their ability to improve the mechanical properties of high solids content polyether and polyester binder types for energetic propellants.

Key Words

Bonding Agents
HMX
RDX
Polymeric coatings
Crosslinked Double-Base Propellants
Nitrate Ester Plasticized Polyethers.

POLYMER MORPHOLOGY STUDY

Minn-Shong Chi

Objective

The objective of this work is to establish a correlation between the structure of the polymeric network and propellant mechanical properties for energetic binder propellants such as cross-linked double-base (XLDB) and nitrate ester plasticized polyether (NEPE).

Results and Conclusions

A significant increase in understanding the polymer structure-mechanical property relationship in binders was obtained in the FY-78 study. A linear relationship between ℓn E (modulus) and ℓn XLD (cross-link density) were obtained for gumstocks of both PEG and PGA systems independent of the cross-linker used. The theoretical relationship of stress, strain and modulus, $\sigma = E/3 \left[(L/L_o) - (L_o/L)^2\right]$, held except for binders containing 18 cps nitrocellulose. A study of the effect of plasticizer (Pl)-to-polymer (Po) ratio indicated that cross-link density in the gel decreased with increasing plasticizer content; the cross-link density dropped dramatically when Pl/Po exceeded 3 in the PEG (N100/CW1000) system. In the current study the effect of varying NC content and stoichiometry on mechanical properties is being investigated to achieve a better understanding of the role of NC in the polymer network. In addition, the plasticizer effect on the XLD and mechanical properties will be studied.

Future Work

During the next report period, propellant binders will be manufactured with varying plasticizer content in PEG (N100/CW4000 and N100/CW6000) and PGA (NC/HDI in R18 and S1011) systems to achieve a better understanding of plasticizer effect on the polymer network and its mechanical properties. The study of gumstocks with solids will be carried out to investigate the solids-binder interaction.

Key Words

Polymer network
Cross-link density (XLD)
XLDB propellants
NEPE propellants

ROCKET MOTOR SIGNATURE EVALUATION

T. E. DURNEY
A. G. MOORE

ROCKET MOTOR SIGNATURE EVALUATION

T. E. Durney
A. G. Moore

INTRODUCTION

During the past several years there has been increasing emphasis on the development of solid propulsion systems yielding low visibility exhausts under tactical conditions. This requirement has been dictated by service experience that clearly demonstrated the effectiveness of evasive actions against smoky missiles and by the increased use of infrared, electro-optical and laser guidance systems that require a "clean" atmosphere for a second shot. More recently, the intensified effort to develop IR/UV sensors capable of remote missile exhaust plume detection has raised the issue of quantifying IR/UV emission intensities and frequencies so that target ships or aircraft might detect them in time to use countermeasures or to take evasive action.

The feasibility of obtaining invisible, noninterfering plumes from ignition to burnout is highly questionable and thus a compromise might be sought. While the compromise is dependent on an accurate definition of the user's requirements for each phase of the flight, it is also dependent on the test method used to assess the signature. The ODDR&E has recognized this problem and has stated "A Method for quantitatively measuring smoke which correlates with flight results and predictions is required."

Also, much more information is required about the feasibility and need for reducing or changing plume IR/UV emissions to nondetectable levels in specific wavelength intervals useful for application of enemy countermeasures.

In development programs of "smokeless" and low IR/UV emissivity rocket propulsion systems it is desirable to perform, as early as possible, a series of tests to define the relative ranking of candidate propellant, motor and ignition materials with regard to visual and IR/UV signatures and E-O sensor or guidance interference. In order to be meaningful, it is necessary to demonstrate that these measurements can be related to full scale missile signatures under actual flight conditions.

It is the purpose of this work to provide insight into this problem by statically testing a series of full scale operational motors and comparing their signatures with that obtained from parallel tri-service simulation (i.e., wind tunnel and ballistic test range), flight test efforts and from Army Signature Characterization Facility tests conducted for both smoke and IR/UV emissions. In the proposed work, scale model motors employing propellants identical to the full scale motors will also be statically tested to define scale factors.

SUMMARY AND CONCLUSIONS

Principal efforts have been devoted to the development of ultraviolet emission measurement equipment suitable for outdoor static test range operation. Preliminary experiments with motors of opportunity showed that far greater detector sensitivity will be required over that tested. Work has started on adapting the various full size tactical test motors to the slanted signature test stand.

DISCUSSION OF EFFORTS

Work during the report period has concentrated on the development of ultraviolet (UV) intensity measuring equipment to complement the existing[(1)] photopic and IR devices. A limited amount of preliminary testing to establish plume UV energy levels for detector circuit amplifier sizing has been conducted. The approach taken for this effort was to interpose a solar blind UV filter (0.263 ± 0.015 μm) between the test motor plume and the detector of a Hewlett Packard Model 8330A Radiometer.

The first test run employed a reduced smoke composite propellant motor (motor of opportunity) having a mass rate of discharge of 17 lbs per second. With the radiometer adjusted for 10 $\mu W/cm^2$ full scale and positioned 130 inches from the plume axis, no detectable signal was received. The experiment was repeated, but with the radiometer positioned 77 inches from plume center line and with a 22% aluminum, 2.5 lb/sec motor located 48 inches away, all with identical negative results. Under these same test conditions, radiometers operating at filtered IR wavelengths (2.692 ± 0.44 μm and 4.59 ± 0.52 μm) would have produced a power of several milliwatts per square centimeter.

This test effort demonstrated the requirement for vastly increased detector sensitivity. To this end, a Hamamatsu photomultipler tube, Model R106VH, was procured and bench tested with an 85-watt GE H85A3/UV mercury vapor radiation source. The 0.2537 μm Hg line was easily detected; however, at this writing, motor firing trials with the increased sensitivity detector have not been accomplished.

Efforts have also started on the design of fixtures to adapt the various tactical motors to the slanted firing stand.

FUTURE WORK

A total of forty scale model and full scale motor firing tests producing data on the photopic and IR transmissivity, photopic reflectivity, and IR/UV emissions is planned for the program. Additionally twelve of these are scheduled to employ the Eglin AFB thermovision recording system. Motors to be employed include Mk 78 and Mk 53 Mod 3 Shrikes, Mk 71 Mod 1 Zuni, Mk 4 Mod 10 FFAR, and Mk 17 Mod 5 Sidewinders.

----

(1) Hercules/ABL Annual Report, "NAVSEA Research and Exploratory Development - 1977" (U), Report No. 4084-101-07-006, dated August 1978, CONFIDENTIAL, DCN-N-70-6.

LOW COST STRIP LAMINATE CASE

D. W. FERTIG
J. M. VILES

LOW COST STRIP LAMINATE CASE

D. W. Fertig
J. M. Viles

INTRODUCTION

Fabrication of metallic tactical rocket motor cases comprises the major portion of overall propulsion system costs. This expense results from the extensive labor and tooling associated with forming, welding, heat treating, and machining round motor tubes and attachments to tight tolerances. Hercules' strip laminate process reduces costs by simple assembly and bonding operations with small finished parts. Machining, welding and heat treatment operations are performed on small, easy to handle parts. Inflationary economic pressures and raw material shortages are forcing material suppliers to turn from high-performance, low-production items to high-volume products to improve profit, making it difficult to find suppliers who will bid on metal tactical missile cases. Hercules' strip laminate capability promises to provide the Navy with a low-cost optional technique for manufacturing large, high-performance rocket motor cases.

The process consists of laminating adhesive-coated, ultra-high strength, 4-in.-wide x 0.012-in.-thick strip steel on an accurately dimensioned mandrel; curing the adhesive-coated laminate; and machining (cutting) tubes to the desired length. Multiple tubes may be made on one long mandrel, and the process is particularly advantageous for small programs since tooling expenses are minimal and the tooling is much less sophisticated than for monolithic metal cases. End closures containing attachment fittings for nozzles, fins or launch lugs are bonded into the laminated tube sections to form the completed vessel. Fabrication procedures are simple and reproducible with the high strength of thin metal strip achieved in the resulting composite chamber.

In the FY-77 program, a 13.5-inch diameter steel strip laminate case was designed and manufactured to demonstrate feasibility of using this type case for NAVSEA rocket motors. The case was constructed by laminating eight layers of 4 in. wide high-strength steel into a tube to form the case cylindrical sections. Aluminum adapter rings were machined and bonded, with a heated cure, into the ends of the tube. The demonstration was not completed because an unsatisfactory bond was obtained between one end ring and the strip laminate tube in the one case made.

The objectives of the FY-78 program are to complete the feasibility demonstration started in the FY-77 program and to make two cases available for the Vertical Launch Controllable Motor Task. Aluminum and steel end ring and closure designs will be evaluated. Strip laminate cases will be

subjected to environmental and structural tests representative of NAVSEA rocket motor environments and handling.

SUMMARY AND CONCLUSIONS

A 3000 psi proof test and 3500 psi hydroburst test demonstrated that aluminum end rings and closures are viable approaches for large diameter steel strip laminate cases. The hydroburst test showed excellent agreement with the structural analysis.

A preliminary design of a case utilizing the Mk 56 rocket motor steel end closure configuration has been prepared for the Vertical Launch Booster demonstration motor task.

DISCUSSION OF EFFORTS

A. Aluminum End Ring Demonstration

Aluminum end rings/closures may provide weight and cost advantages for some applications. Feasibility of using aluminum end rings was demonstrated with a successful proof and hydroburst test. A 13.5-in. diameter case was fabricated by bonding aluminum end rings in a steel strip laminate cylinder as shown in Figure 1. A steel reinforcement sleeve was added after the case was fabricated to prevent rolling and premature ejection of the closure retainer ring.

A structural analysis indicated that the reinforcement was required and that simply extending the steel strip laminate cylinder over the area of the retainer ring would provide adequate stiffness in future cases. The analysis also indicated that the aluminum ring would be stressed beyond the ultimate strength in the area extending approximately two inches from the innermost, feather edge at the 3750 psi design pressure.

The case was proof tested at 3000 psi for 30 sec, depressurized and repressurized to failure at 3500 psi. Component inspection indicated that failure initiated as predicted in the analysis with a hoop failure in the feather edge of the end ring which lead to adhesive failure in the end ring bond joint. The end ring was ejected with no apparent damage to the strip laminate cylinder.

Excellent agreement was obtained with the finite element structural analysis. During the next report period a case will be tested with the feather edge thickness increased and with the aluminum ring reinforced by the strip laminate cylinder. Maximum performance in the bonded joint requires a balance between stresses in the adhesive and in the end ring so that strain mismatch is minimized, i.e., a more uniform distribution

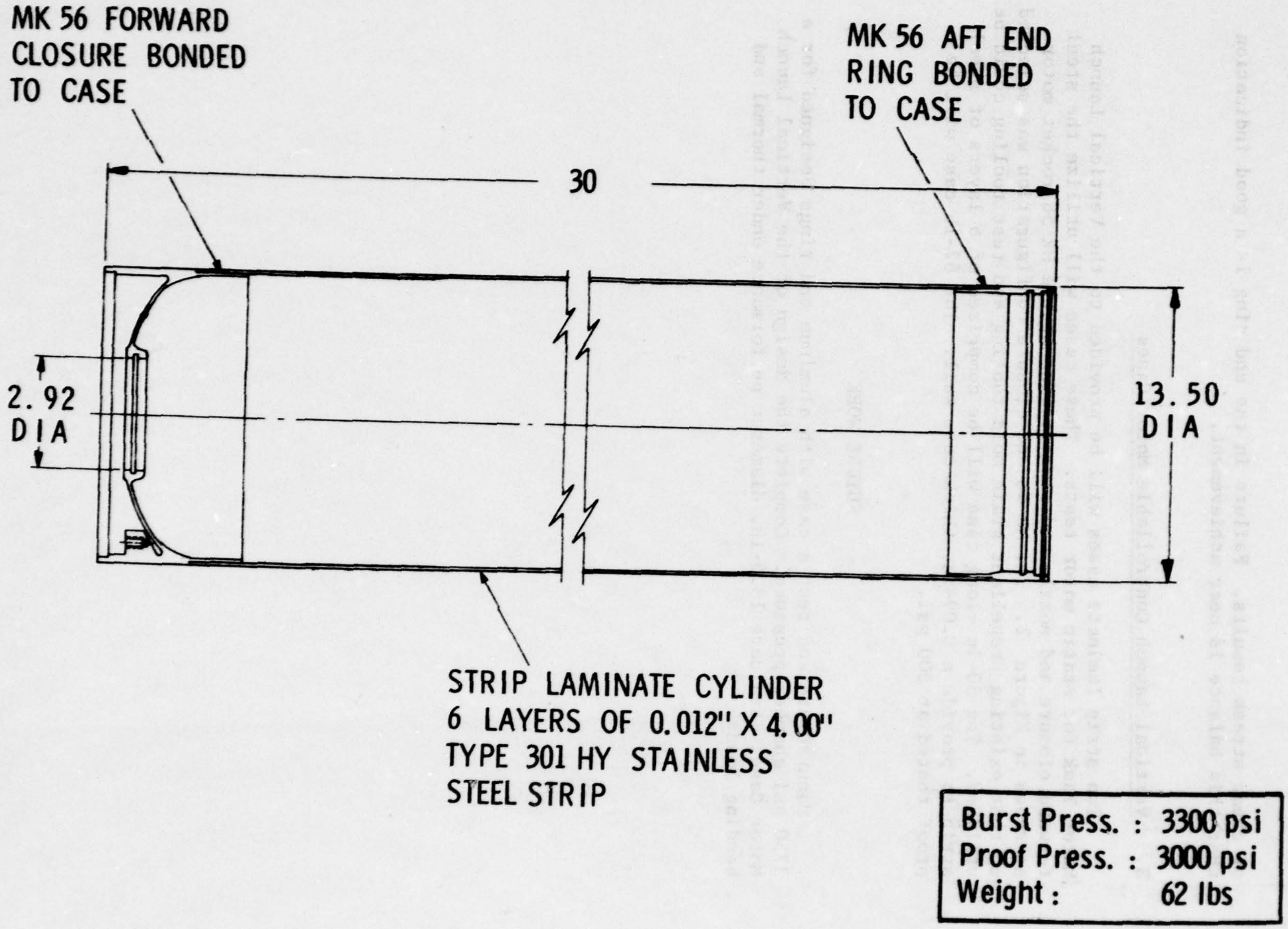


Figure 1. Low-Cost 13.5-in. Diameter Strip Laminate Case

of shear stress results. Failure in the end ring is a good indication that this balance is near achievement.

B. Vertical Launch Controllable Motor Cases

Two strip laminate cases will be provided to the Vertical Launch Motor Task for static motor tests. These cases will utilize the steel forward closure and nozzle end ring designs of the Mk 56 rocket motor as shown in Figure 2. The Mk 56 end closure configuration was selected so that existing propellant grain mold tooling and test tooling could be utilized. The 30-in.-long case will be comprised of 6 layers of steel strip to provide a 0.09-in.-thick case wall. The 62-lb case will be proof tested at 300 psi.

FUTURE WORK

Manufacture and test a case with aluminum end rings designed for a 3750 psi chamber pressure. Complete the design of the Vertical Launch Motor Case. Evaluate 13.5-in. diameter performance under thermal and bending loads.

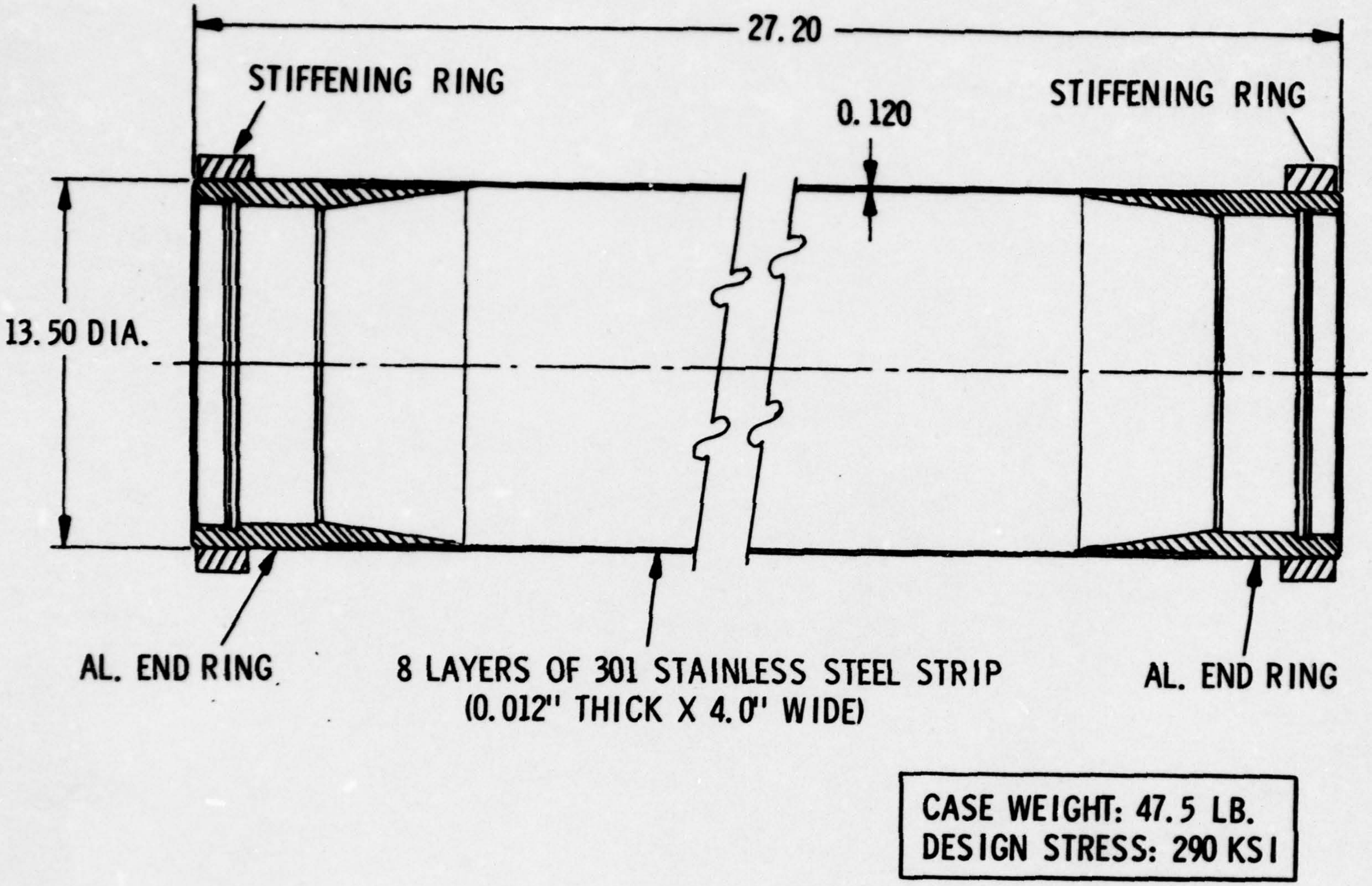


Figure 2. Vertical Launch Controllable Motor

VERTICAL LAUNCH CONTROLLABLE MOTOR

E. D. CASSEDAY

VERTICAL LAUNCH CONTROLLABLE MOTOR

E. D. Casseday

INTRODUCTION

Vertical launch of Navy missiles using a common propulsion/control module offers a low-cost solution to a proliferation of individual vertical launch devices for related propulsion tasks. Launch missions which are candidates for the use of a common controllable launch motor include Standard Missile-MR, Harpoon, ASROC and Tomahawk. This task is part of a multi-year effort to develop the technology required for the controllable launch motor. Technologies which are to be evaluated include:

(1) A minimum-smoke cross-linked slurry-cast double-base propellant.

(2) Strip laminate low-cost case.

(3) Thrust termination for impulse control.

(4) Thrust vector control system for trajectory control.

Previous effort (FY-78) included tailoring of a smokeless XLDB propellant for higher r_{1000} burn rate, 0.5 to 0.6 in/sec, from the state-of-the-art 0.3 to 0.4 in/sec, while maintaining acceptable performance and mechanical properties. Propellant GCJ containing a Pb_2O_3 + ZnO modifier system was evolved during this study; however, burn rate was lower than desired and pot life was marginal. Late in the FY-78 program the use of all-cotton linter NC gave a significant improvement in pot life. Hercules' IR&D studies have identified Pb Sebacate as a promising modifier for high burn rate. It is planned to evaluate the combination of Pb Sebacate and ZnO in conjunction with all-cotton linter NC in one-pound mixes prior to the propellant acceptance 5-gal mix included in this year's program.

The primary objective of this year's program is the manufacture and static firing of at least two full-scale motors using test weight hardware.

SUMMARY AND CONCLUSIONS

Effort to date has consisted of detailed program planning using results from last year's propellant and the low cost strip laminate case tasks. It is planned to design, manufacture and test two demonstration motors. These motors will use strip laminate tube cases with adhesive bonded joint Mk 56 case configuration forward domes and aft rings which

contain smokeless XLDB propellant grains. The successful accomplishment of the two planned static firings will demonstrate (1) strip laminate case integrity, (2) full-scale motor performance, and (3) propellant extinguishment characteristics.

A flightweight motor design having (1) a submerged nozzle/TVC system, and (2) a thrust termination system will also be prepared for use in next year's program.

DISCUSSION OF EFFORTS

A. Technical Approach

The technical approach will be to combine existing smokeless propellant and strip laminate case technologies into a motor design which will be manufactured and tested to validate the basic concepts required for a vertical launch controllable motor.

Effort will include (1) insulated case design, (2) propellant grain design, (3) nozzle design, (4) casting hardware design/procurement, (5) insulated strip laminate case manufacture, (6) propellant grain manufacture, (7) motor final assembly, and (8) motor static firing/postfiring inspection/performance analysis.

The following parameters have been selected for use in test motor design studies:

Size

Outer Diameter = 13.5 in.
Length = 30 in.

Performance

Total Impulse	As defined in NWC Vertical Launch
Burn Time	Propulsion Technology Quarterly Reports[1]
Thrust Profile	- Neutral within ± 15%

More detailed planning information is presented below.

B. Program Plan and Schedule

A detailed program schedule for this year's effort is shown as Figure 3. Planning is directed toward the manufacture and static firing of two motors using test-weight hardware plus conducting detailed design studies to define a flightweight motor configuration for manufacture and testing next year.

---

(1) Naval Weapons Center/China Lake Propulsion Review - Air Breathing and Solid Propulsion Research and Exploratory Development, April thru June 1978 (U) (CONFIDENTIAL), NWC TP 4100-50, June 1978.

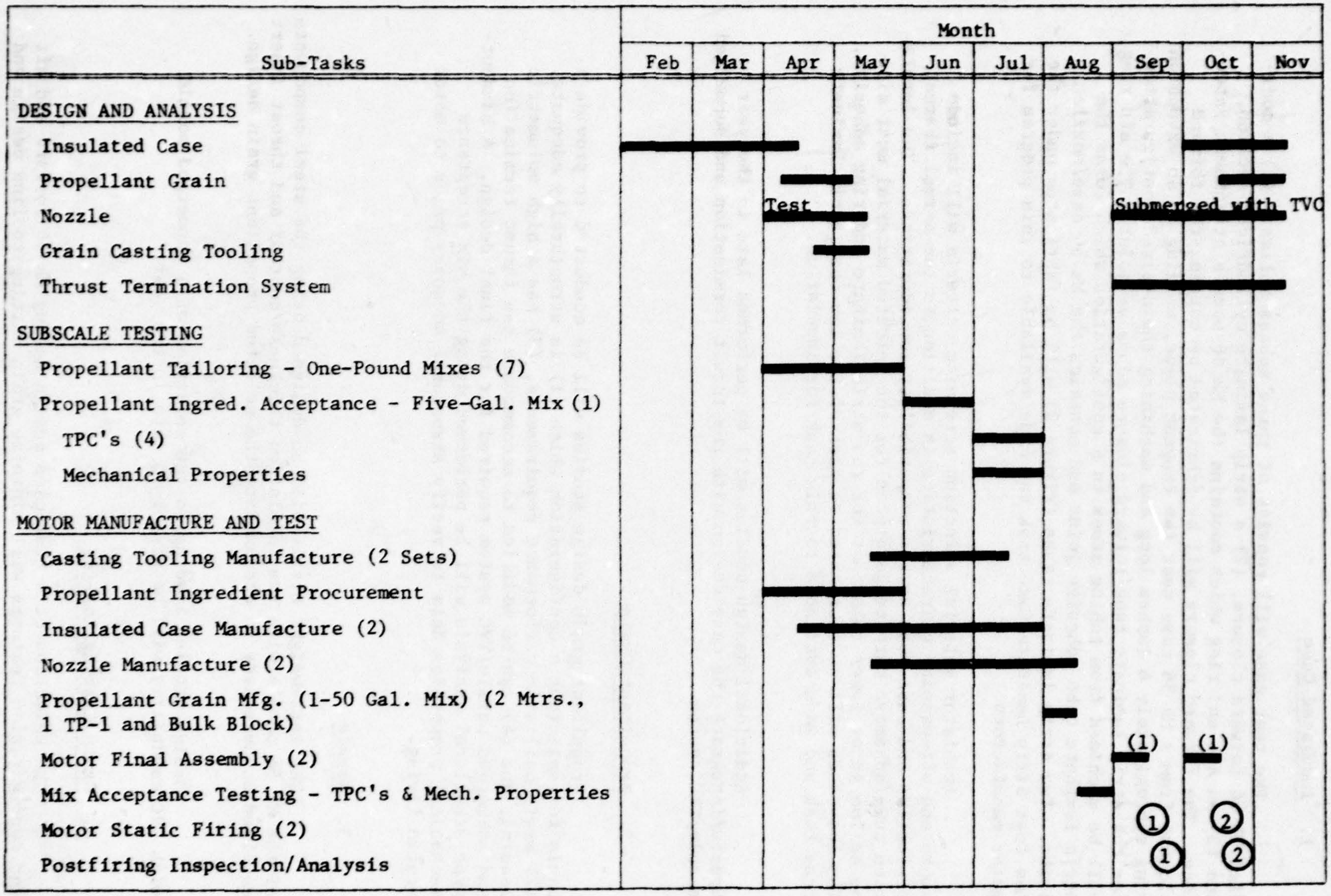


Figure 3. Vertical Launch Controllable Motor Program Schedule

1. Insulated Case

The test case will consist of three subassemblies: (1) a modified Mk 56 forward closure, (2) a strip laminate cylindrical section, and (3) an aft end ring which contains the Mk 56 nozzle attachment interface. The forward closure will be fabricated by cutting the forward closure from a Mk 56 case near the tangent plane, welding on an extension ring approximately 6 inches long and machining the desired configuration for the strip laminate tube/forward closure adhesive joint. The aft ring will be machined from tubing stock to a configuration which forms the strip laminate tube adhesive joint and contains the Mk 56 case/nozzle joint. Two strip laminate cases (Figure 2) will be fabricated under the Low Cost Strip Laminate Case task and made available to this program for motor manufacture.

Insulator material selection screening criteria will include smoke and off-gassing characteristics in addition to the normal thermal protection and case bond system compatibility considerations. The insulation cure/adhesive cure temperatures for the selected material must also be as low as or lower than that for the strip laminate end ring adhesive. The two cases will be fabricated as part of the low-cost strip laminate case task and made available to this task for insulation.

Additional design studies will be performed late in the year to update/integrate the case design with the thrust termination and submerged nozzle/TVC system.

2. Propellant Grain

Propellant grain design studies will be conducted to provide a basis for selecting a configuration which (1) is structurally adequate, (2) meets ballistic performance requirements, (3) has a high volumetric loading, and (4) can be modified to accommodate the thrust termination and submerged nozzle/TVC system required for the final design. A handout-type structural analysis will be performed using the mix acceptance mechanical properties data to verify structural adequacy prior to motor static firing.

3. Nozzle

The test-weight nozzle will be designed using the steel components of the Mk 56 nozzle with the insulation thickness/contour and throat insert modified as necessary to accommodate the selected propellant grain design.

Design studies leading to the selection of a submerged nozzle with TVC capability will be performed late in the year.

4. Grain Casting Tooling

The selection of a test-case design having Mk 56 forward and aft end configuration features will minimize grain casting tooling design and

fabrication cost in that existing tooling other than the center core and case length related items can be used. Upon selection of the grain configuration, two cores and associated components will be designed and fabrication drawings prepared.

5. Thrust Termination System

A thrust termination system will be designed using Hercules' extensive experience (Polaris, Minuteman and Trident) to select a viable concept. In addition to cost, weight, safety/reliability and volumetric packaging efficiency considerations, the design study will also address the attainment of the widest feasible range of actuation time and methods for outboard venting of any debris and blowdown propellant gases.

6. Subscale Testing

A series of one-pound mixes will be made to evaluate improvements in propellant formulation GCJ which was developed during the FY-77 program. Specific areas to be evaluated include (1) the use of all-cotton linter NC for potlife improvement, and (2) the use of Pb Sebacate + ZnO to increase burn rate. Propellant from each mix will be allocated for strand burn rate and mechanical properties testing. The data obtained will be used as the basis for selecting the propellant formulation to be scaled up to the 5-gal propellant ingredient acceptance mix.

The 5-gal propellant ingredient acceptance mix will be made using the same ingredients (including lacquer mix) that are subsequently scheduled to be used in the 50-gal motor mix. Ingredient acceptance will be made on the basis of burn rate (4 TPC's) and mechanical properties data.

7. Motor Manufacture and Test

This sub-task includes all of the effort required to manufacture and test two demonstration motors. Preparatory effort includes (1) the manufacture of two mold cores and associated components, (2) procurement of propellant ingredients, (3) insulation of two strip laminate cases, and (4) the manufacture of two nozzle assemblies. Propellant from the 50-gal mix will be allocated to casting the two demonstration motors, one TP-1 and a bulk propellant sample. Mix acceptance testing will include firing four TPC's for burn rate and determining propellant mechanical properties at three temperatures.

The first motor will be assembled using a bag igniter and a nozzle with the throat sized on the basis of mix acceptance TPC data. It is planned to static fire this motor at 77°F to demonstrate (1) strip laminate pressure vessel integrity, and (2) full-scale motor performance. Results of the first firing will be used to make any necessary design changes (e.g., igniter charge or nozzle throat size) prior to final assembly of the second motor.

Contingent upon the attainment of all test objectives with the first motor, it is planned to terminate thrust at two-thirds of the burning time by cutting off the aft end of the motor with a linear-shaped charge to demonstrate propellant extinguishment characteristics.

FUTURE WORK

Finalize the demonstration motor design and manufacture and test two demonstration motors as outlined in the program schedule.

PREDICTION OF XLDB PROPELLANT MECHANICAL FAILURE

G. E. HERRIOTT

PREDICTION OF XLDB PROPELLANT MECHANICAL FAILURE

G. E. Herriott

INTRODUCTION

Effort during this report period involved the formulation of the detailed program plan. This report discusses that program plan.

Because one of the primary failure modes for rocket motors involves propellant grain cracking during low temperature storage, it is desirable to be able to predict the conditions for that failure from relatively simple and inexpensive tests. A first step in that direction was obtained in the FY-78 effort in which uniaxial tensile properties were compared to the failures induced in strain evaluation cylinders (SEC's) which had been shock cycled. The purpose of the FY-79 effort is to continue this study such that the criteria for propellant failure under low temperature storage can be more accurately predicted.

The objective of the effort is therefore to establish correlations between propellant mechanical property tests and rocket motor behavior such that propellant grain failure in a rocket motor under low temperature storage conditions can be reliably predicted.

SUMMARY AND CONCLUSIONS

During the past report period, data from the FY-78 study was reviewed and a program plan for the FY-79 effort was formulated.

Three propellants with various stress-strain behaviors typical of current state-of-the-art propellants will be step-cooled to failure in strain evaluation cylinders (SEC's). This failure behavior will then be compared to mechanical property test results. The time dependent strain endurance capabilities of the propellants will be characterized in particular since long term strain induced failure is the primary mode of failure for the step-cooled SEC's. Uniaxial strain endurance will be determined at various temperatures and conditioning histories. To provide strain endurance data under conditions more closely simulating those in a low temperature conditioned rocket motor, a multi-axial strain endurance test will be developed. The feasibility of such a test has been demonstrated under exploratory IR&D work by Hercules. Other uniaxial mechanical properties will also be obtained to provide the necessary characterization data for the propellants. It is expected that correlation of the uniaxial and multi-axial test data with the SEC failure data will result in a technique to predict the failure conditions for a rocket motor under low temperature storage conditions.

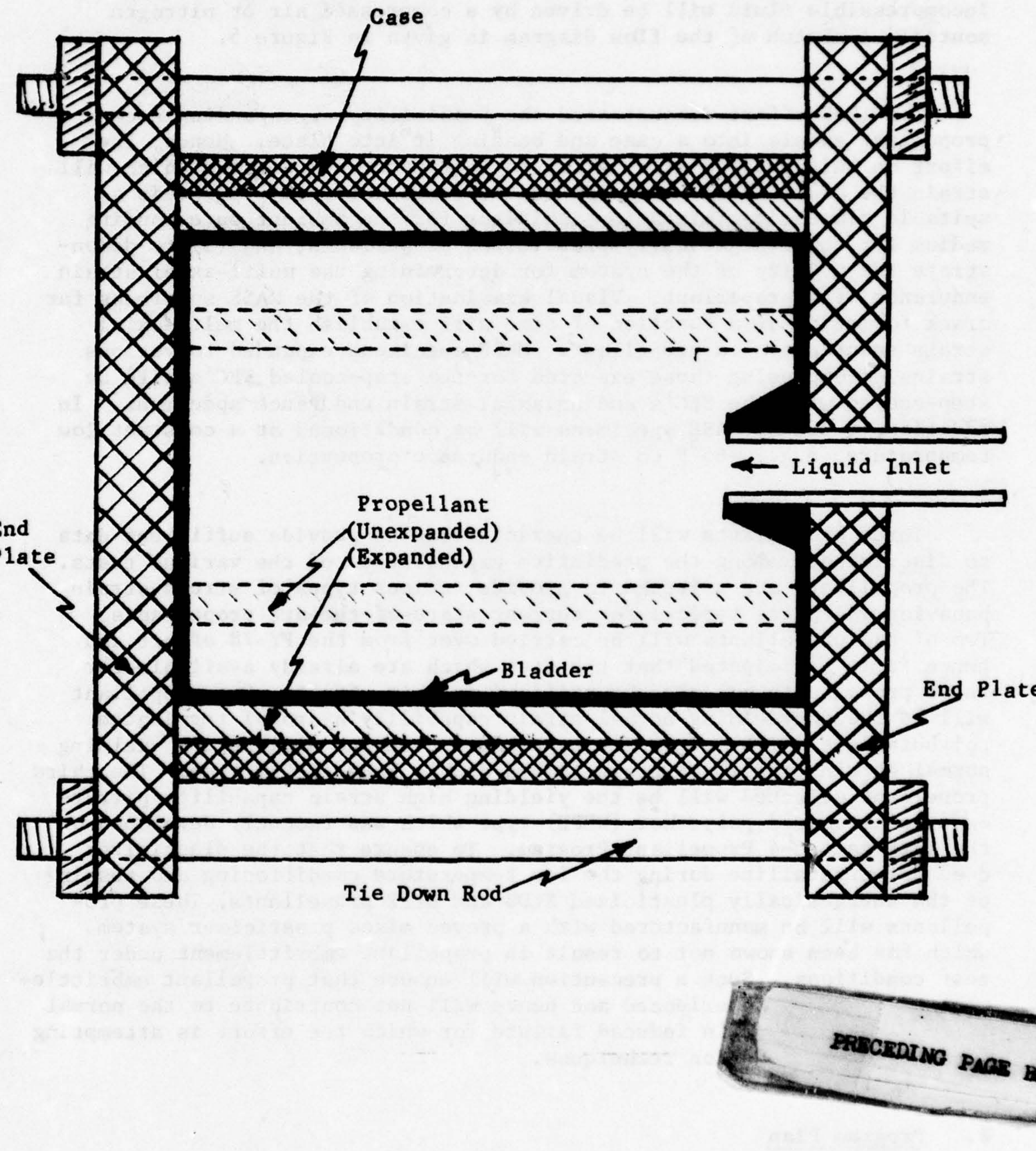


Figure 4. Expansion Chamber for Multi-Axial Strain Endurance (MASE) Specimen

PRECEDING PAGE BLANK

A noncompressible fluid will be used to inflate the bladder such that the rate of bladder and hence propellant strain rate can be accurately and reproducibly controlled. It is anticipated that the incompressible fluid will be driven by a compressed air or nitrogen source. A sketch of the flow diagram is given in Figure 5.

The IR&D effort demonstrated the feasibility of expanding such a propellant sample into a case and bonding it into place. Hence, the effort on this program will be (1) to fabricate an apparatus which will strain the sample at a known and reproducible rate, (2) to obtain a suitable plasticizer migration inhibitor for the ambient cure bonding medium for the energetically plasticized propellants, and (3) to demonstrate the utility of the system for determining the multi-axial strain endurance of a propellant. Visual examination of the MASE specimens for crack formation as a function of time will establish the multi-axial strain endurance of a propellant. MASE specimens expanded to various strains encompassing those expected for the step-cooled SEC's, will be step-cooled with the SEC's and uniaxial strain endurance specimens. In addition, a set of MASE specimens will be conditioned at a constant low temperature, e.g., -65^{o}F to strain endurance properties.

Three propellants will be characterized to provide sufficient data to discriminate among the predictive capabilities of the various tests. The propellants are selected to provide various types of stress-strain behavior which are typical for current state-of-the-art propellants. Two of the propellants will be carried over from the FY-78 effort and hence it is anticipated that the data which are already available for these propellants can also be utilized in this effort. One propellant will be the nonyielding normal strain capability hydroxyl terminated polybutadiene (HTPB) composite type and the second will be the yielding normal strain capability cross-linked double base (XLDB) type. The third propellant selected will be the yielding high strain capability nitrate ester plasticized polyether (NEPE) type which was recently developed on the Alternate C-4 Propellant Program. To ensure that the plasticizer does not crystallize during the low temperature conditioning and testing of the energetically plasticized XLDB and NEPE propellants, These propellants will be manufactured with a proven mixed plasticizer system which has been shown not to result in propellant embrittlement under the test conditions. Such a precaution will ensure that propellant embrittlement will not be experienced and hence will not contribute to the normal low temperature strain induced failure for which the effort is attempting to establish prediction techniques.

B. Program Plan

The FY-79 program is divided into two phases. Phase I will consist of fabrication and check-out of the MASE apparatus and techniques. Phase II will involve the characterization of the three selected propellants by step-cooled SEC's, uniaxial properties and MASE specimens and the correlation of the data to provide motor failure prediction

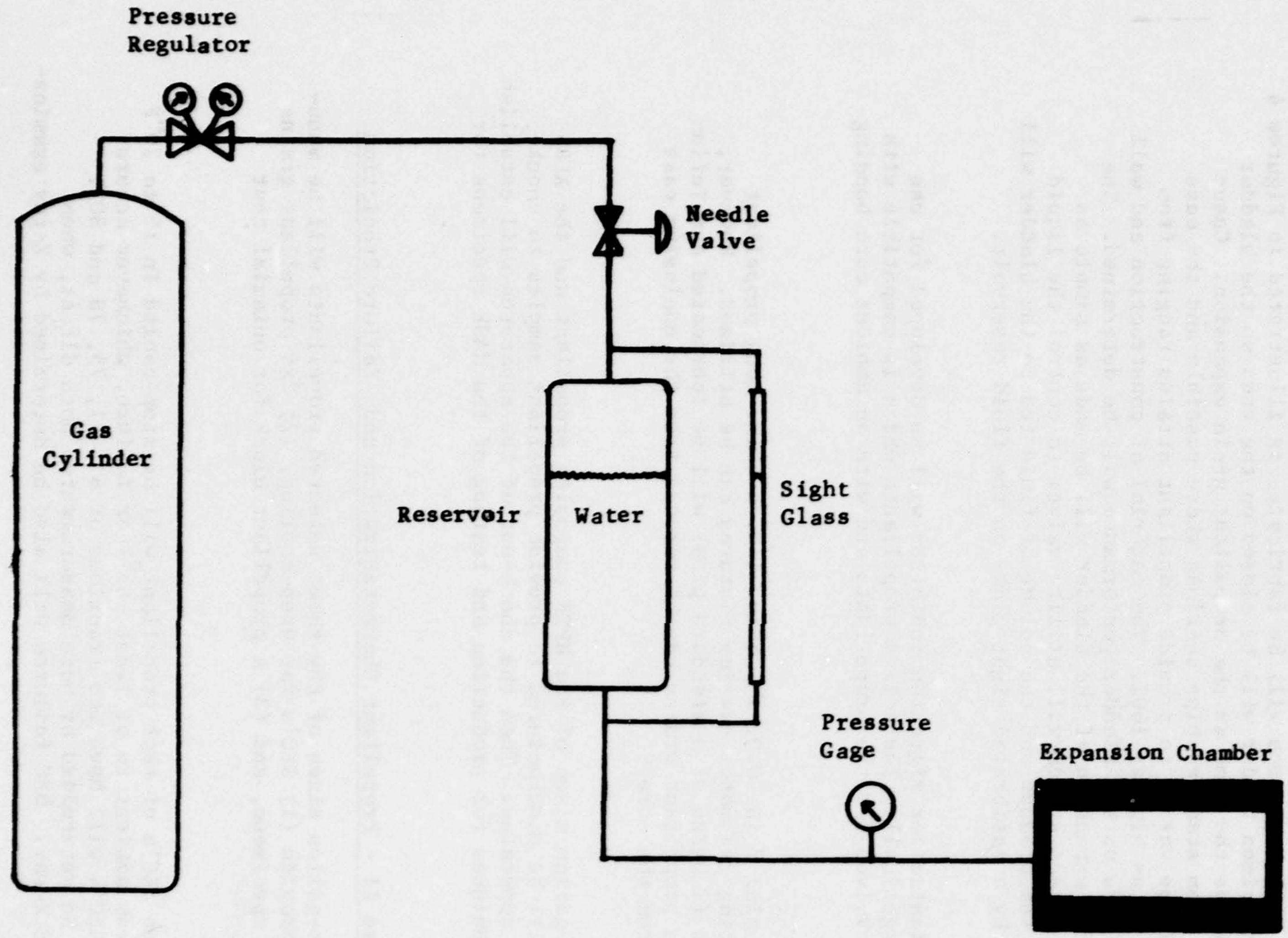


Figure 5. Flow Diagram for Multi-axial Strain Endurance (MASE) Apparatus

techniques for low temperature storage conditions. A program schedule is shown on Figure 6.

1. Phase I - MASE Apparatus

The MASE apparatus will be fabricated as illustrated in Figures 4 and 5. The specimen holder will be closed on the ends so the bladder expansion will be the same as the propellant grain expansion. Cases will be made from standard pipe sections where possible and the case diameters will be varied to provide propellant strains ranging from about 10% up to as high as 100%. The material of construction and wall thickness effects on the bladder performance will be determined. The feed system for expansion of the bladder will be made as simple as possible. The feed system will utilize valves to control the liquid feed rate to the bladder and the volume of fluid fed to the bladder will be monitored by a calibrated sight glass on the fluid reservoir.

A plasticizer migration inhibitor will be developed for use with the energetically plasticized propellants which is compatible with the strain involved for the propellants and with an ambient cure bonding requirement.

By using 2 in. O.D. x 1.5 in. I.D. x 4 in. long propellant grains, existing 2x4 motor casting fixtures can be utilized. However, casting tubes (lengths of a standard pipe) will be fabricated and Teflon coated so the propellant grains can be removed from the enclosing case as well as from the core.

One-gallon mixes of the HPTB composite propellant and the XLDB propellant will be manufactured to provide propellant samples to check-out the MASE apparatus. Then the check-out of the apparatus will establish standard techniques for production and testing of the MASE specimens for Phase II.

2. Phase II - Propellant Characterization and Failure Prediction

Five-gallon mixes of the three selected propellants will be manufactured to provide (1) SEC's for step-cooling, (2) 2x4 propellant grains for the MASE specimens, and (3) a propellant block for uniaxial test specimens.

Seven SEC's of each propellant will be step-cooled in 15 to 20°F increments from ambient to at least -65°F or failure, whichever occurs first. The SEC's will have web fractions of 67, 71, 75, 78 and 80%. Strains will be determined by bore measurements, both direct, when possible, and X-ray. SEC failures will also be determined by X-ray examinations.

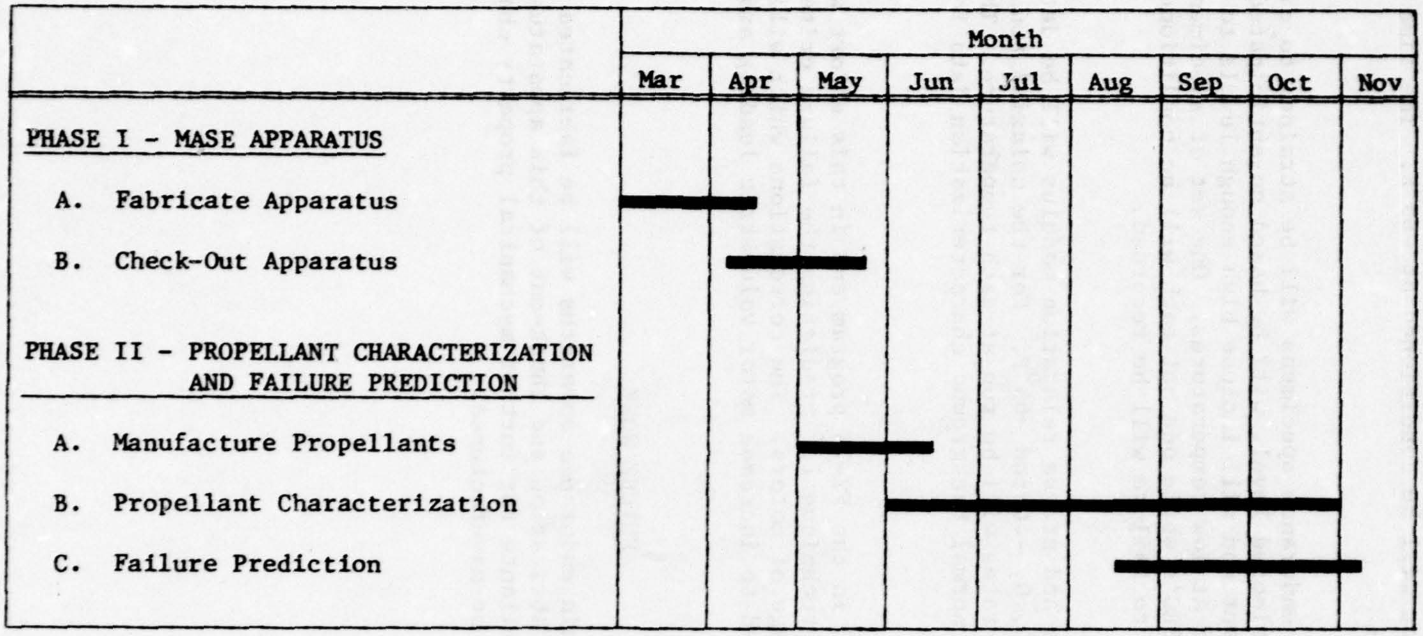


Figure 6. Program Schedule for Prediction of Propellant Mechanical Failure

The MASE specimens will be strained to five different levels. The selected levels will be based on the anticipated SEC strains for each propellant. One set of MASE specimens will be step-cooled with the SEC's while the second set will be conditioned at -65°F. The time to failure will be recorded.

The uniaxial strain endurance specimens will be strained to eight different levels. The selected levels will be based on anticipated SEC strains for each propellant and will include high enough levels to ensure that failure are obtained at low temperatures. One set of specimens will be step-cooled with the SEC's while one set each will be conditioned at -40 and -65°F. The time to failure will be recorded.

The uniaxial tensile and stress relaxation modulus will be determined at 165, 120, 77, 40, 0, -40 and -65°F. For the uniaxial tensile properties, three strain rates will be run at each temperature. These propellants will provide normal background characterization data for the propellants.

The data accumulated in the FY-78 program and in this effort will be analyzed to provide a technique for predicting the failure criteria for low temperature storage of motors. The correlations which will be developed may then be used to increase motor volumetric loading and performance.

FUTURE WORK

The multi-axial strain endurance apparatus will be fabricated and checked-out. After the fabrication and check-out of this apparatus is well under way, the propellants for further mechanical property characterization and analysis will be manufactured.

HMX (RDX) BONDING AGENTS

M. T. DONOHUE
J. R. GALLION

HMX (RDX) BONDING AGENTS

M. T. Donohue
J. R. Gallion

INTRODUCTION

The range of Navy missile systems can be increased significantly by employing cross-linked double-base (XLDB) propellants which contain large amounts of the solid oxidizer cyclotetramethylenetetranitramine (HMX) or cyclotrimethylenetrinitramine (RDX). However, as the oxidizer level increases in a propellant, slurry viscosity increases and overall mechanical properties deteriorate. Both problems could be remedied if a coarse particle size oxidizer which bonds to the binder phase could be utilized. One approach to this remedy is the development of a bonding agent for the coarse HMX or RDX particle.

In the FY-77 program, a series of polymeric coatings were identified as potential HMX bonding agents and a technique for applying the coatings was developed. The most promising polymers were identified as cross-linked polyurethane derivatives of glycerol and a diol comonomer cured with hexamethylene diisocyanate (HDI), and a polyurea derivative of tetraethylene pentamine cured with HDI. The coating technique involved the deposition of the reactive monomers onto the HMX surface from an emulsion system, followed by the addition of curative. The polymerization thus took place at the HMX surface and the particle was uniformly coated with cross-linked polymer.

The FY-78 program was concerned with the characterization of the polymeric HMX bonding agents developed in the FY-77 program and the effect of these bonding agents on the mechanical properties of high solids content XLDB propellants. The significant findings were:

(1) The bonding agents did improve the cured propellant mechanical property balance when compared to a similar formulation incorporating uncoated HMX.

(2) The mechanism of the bonding agent activity was identified as a delaying of the onset of propellant-to-binder dewetting and a transfer of imposed mechanical stress to the HMX crystal during the application of external stress.

(3) Higher cross-link density polymeric coatings on the HMX or RDX are needed to prevent mechanical abrasion of the coating during high shear propellant mixing operations.

The current program is designed to improve the bonding agent toughness and thus overcome the high shear mixing weakness. It also includes the investigation of suitable bonding agents for RDX and an investigation of the effectiveness of coated RDX in improving the overall mechanical properties of high solids content NEPE propellant formulations. Since the crystal structure and surface chemistry of the two oxidizers (HMX and RDX) are similar, it is projected that the coatings already successfully applied to HMX should be equally suited to RDX.

SUMMARY AND CONCLUSIONS

It has been demonstrated that bonding agents for HMX can be developed which improve the mechanical properties of XLDB propellant. Also, a viable method of applying the agent has been developed but the toughness of the bonding agent must be improved for it to survive the shear forces during mixing. Two approaches to this problem are being pursued: (1) increasing the cross-link density by utilizing the comonomer system glycerol-ethylene glycol, and (2) increasing the glycerol to dipropylene glycol ratio while increasing the HDI curative-to-monomer hydroxy ratio which will also increase cross-link density of the bonding agent.

DISCUSSION OF EFFORTS

Recently, emphasis has been placed on the utilization of RDX as a replacement for the more costly HMX as the solid oxidizer in XLDB systems. Therefore, the concurrent objectives of the present program will be carried out primarily with RDX as the subject oxidizer.

Two approaches are being taken in an effort to improve the abrasion resistance of the coatings by increasing the effective crosslink density of the coating polymer. In the first approach, the dipropylene glycol comonomer (with glycerol) is being replaced with the lower equivalent weight ethylene glycol comonomer. The overall effect of this substitution is an increase in the equivalence ratio of the triol comonomer (glycerol) to the diol comonomer. Such an increase in the overall hydroxyl functionality of the system produces the desired increase in polymer crosslink density, and is projected to produce tougher coatings. This approach is being coupled with an increase in the curative-to-hydroxyl (NCO/OH) ratio in the coating formulation as a method of achieving even higher crosslink densities (The effectiveness of the HDI cured glycerol/ethylene glycol polymer system in improving the mechanical properties of FZO type propellant manufactured with coarse HMX particles was demonstrated in the FY-77 program).

The second approach to improved abrasion resistance involves an increase in the glycerol-to-dipropylene glycol ratio of the current "best" bonding agent system coupled with an increase in the HDI curative-to-monomer hydroxyl ratio. While the net effect of this approach is similar to that

of the first approach, the retention of dipropylene glycol as a comonomer is expected to yield bonding agent films which retain a moderate degree of flexibility. (It is recognized that a limit exists in the weight ratio of glycerol-to-dipropylene glycol which cannot be exceeded without changing the surface tension properties of the monomer mixture to the extent where they no longer wet the RDX surface).

Both modified polymer systems are being applied to coarse (> 100μ) RDX crystals obtained by screening commercial feedstock. The quality of the coatings is being examined by the resistance they impart to RDX solution by solvents, and by scanning electron microscope examination for coating uniformity. The coatings which are judged to be satisfactory will be incorporated into high solids content NEPE propellants, and the resulting propellants tested to detect mechanical property improvements.

FUTURE WORK

After obtaining sufficient coated RDX, the material will be incorporated into a NEPE binder system and mechanical properties obtained. Optical and electron microscope studies will be carried out on the coated oxidizer and on the fractured surface of the strained samples. The most promising bonding agent polymers will be applied to larger batches of RDX crystals which will then be utilized in the manufacture of one-pound propellant mixes. Uncoated RDX formulations will be manufactured to provide baseline values for mechanical properties.

POLYMER MORPHOLOGY STUDY

MINN-SHONG CHI

POLYMER MORPHOLOGY STUDY

Minn-Shong Chi

INTRODUCTION

The objective of this program is to more fully understand the relationship between polymer structure and mechanical properties in cross-linked double-base (XLDB) and nitrate ester plasticized polyether (NEPE) systems.

The high performance of cross-linked double-base XLDB propellants arises from high solids loading and high plasticizer (nitroglycerin) content. To achieve such a high performance in systems with optimum mechanical properties, tough polymeric binders are needed. Although the current binder systems were developed to have improved toughness and mechanical properties, the polymer networks of these systems remain largely unknown and they are so complex that almost all inferences are open to challenge. The understanding of the structure-properties relationships is essential to design a satisfactory polymeric binder in propellants which will not granulate under high rate failure conditions and yet have the highest performance possible. A number of techniques such as gel content, cross-link density, C-13 NMR spectroscopy, gel permeation chromatograph (GPC), scanning electron microscopy (SEM) and/or transmission electron microscopy (TEM) and X-ray diffraction will be used to study the polymer network.

SUMMARY AND CONCLUSIONS

A significant increase in understanding the polymer structure-mechanical properties relationship in propellant was obtained in the FY-78 study. In this fiscal year (1979), efforts are being directed toward defining the effect of plasticizer levels on XLD and mechanical properties. In addition, the effect of the combination of NC content and stoichiometry on mechanical properties is being studied. The effect of solids loading on binder properties is also being investigated.

DISCUSSION OF EFFORTS

In FY-78 the program was focused on varying prepolymer molecular weight (PEG and PGA), cross-linker functionality, nitrocellulose (NC) and plasticizer concentration. An increased understanding of polymer structure and its mechanical properties in binders was achieved during the FY-78 study. A linear relationship between $\ell n\ E_o$ (modulus) and ℓn XLD (cross-link density), $[\ell n\ E_o = -6.083 + 0.815\ \ell n\ XLD]$ (Figures 7 and 8), was obtained for gumstocks of both PEG and PGA systems independent of the crosslinker used. The theoretical relationship for stress, strain and modulus, $\sigma = E/3\ [(L/L_o)-(L_o/L)^2]$, held except for binders containing 18 cps nitrocellulose (Figure 9). A study of the effect of

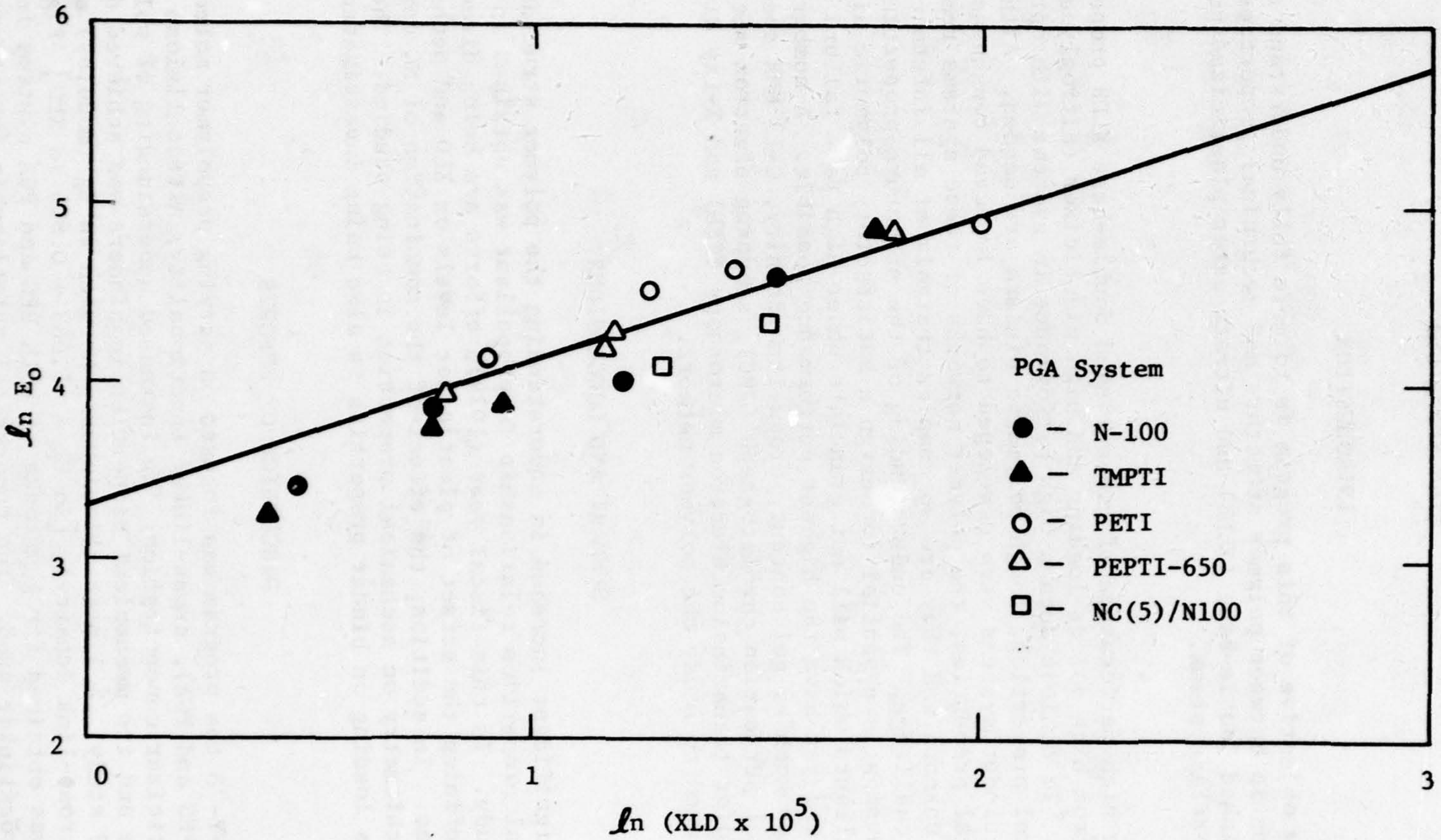


Figure 7. The Relationship between $\ell n\, E_o$ and ℓn XLD in PGA System

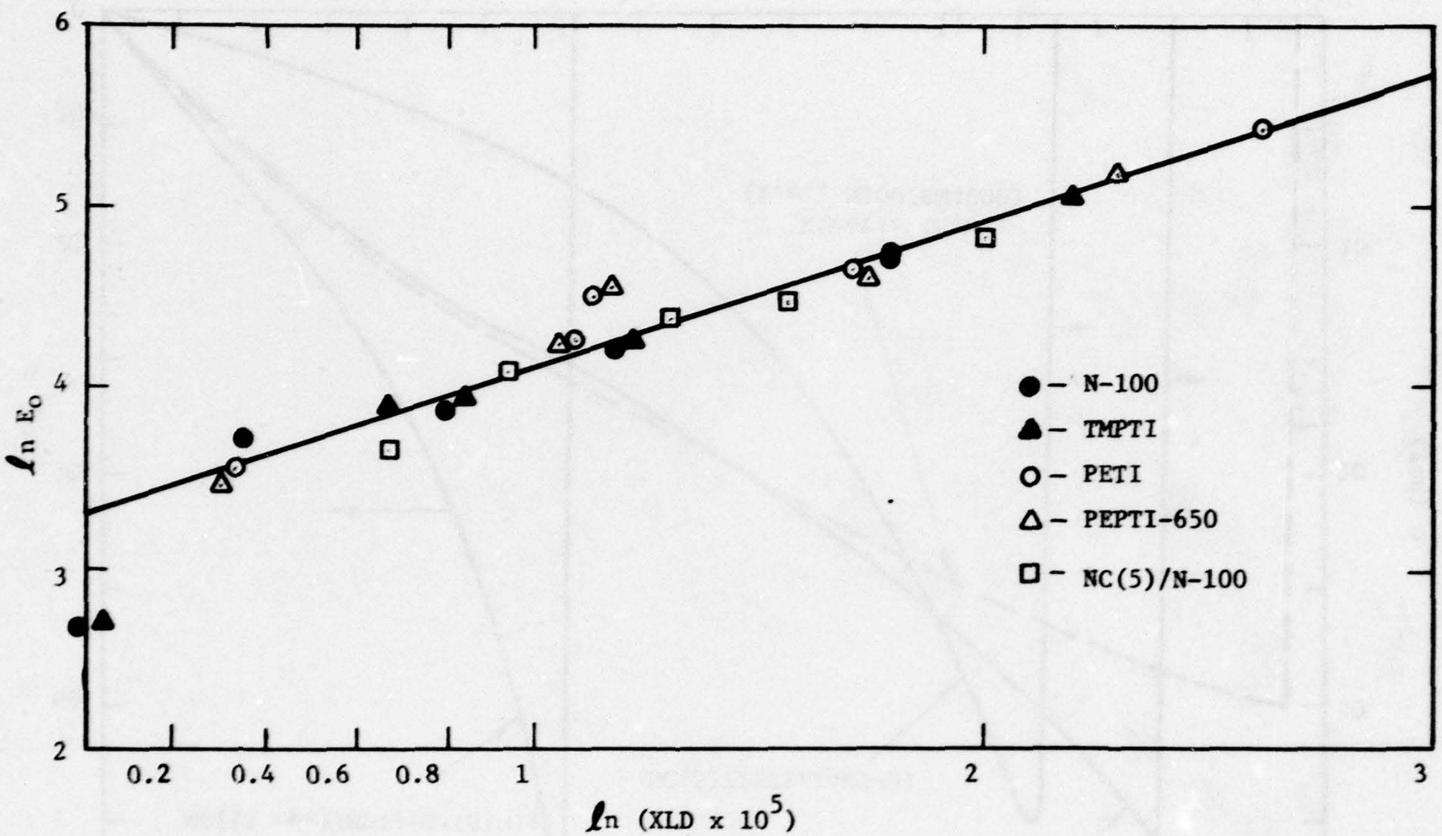


Figure 8. The Relationship Between ln E_o and ln XLD in PEG System

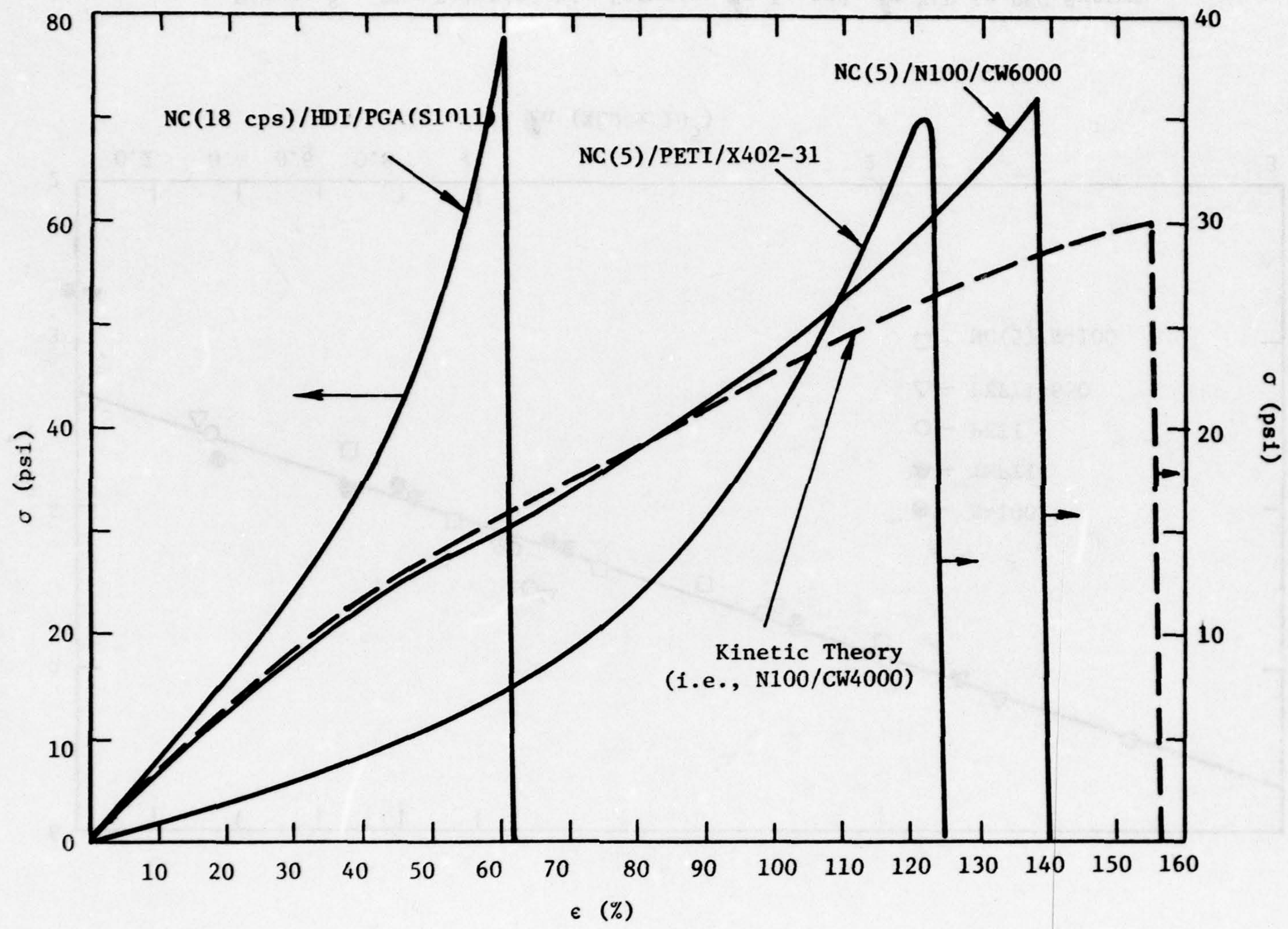


Figure 9. Stress-Strain Curve for Various Gumstocks vs. Kinetic Theory

plasticizer (Pl)-to-polymer (Po) ratio indicated that cross-link density in the gel decreased with increasing plasticizer content; the cross-link density dropped dramatically, when Pl/Po exceeded 3 in the PEG (N100/CW1000) system (Figure 10). NC (18 cps)/HDI was found to give higher modulus and stress for the PGA system than for the PEG system. This observation is probably due to the fact that the reactivity of hydroxy groups of PGA is higher than the hydroxy groups of PEG.

A number of techniques have been used to determine the polymer structure, including gel content, cross-link density, C-13 spectroscopy, gel permeation chromatography (GPC) and scanning electron microscopy (SEM). The above-mentioned techniques, accompanied by the transmission electron microscopy (TEM) technique, will be used to elucidate the polymer structure in the current studies.

NC (nitrocellulose) and CAB (cellulose acetate butyrate) are known to be good cross-linker aids when used in combination with HDI or N-100. However, their effect on the polymer network remains largely unknown since NC and CAB molecules are very complex. Since both NC and CAB are high molecular weight and high functionality, there is the possibility that they form "domains" which enforce the polymer network. Table I lists the formulations for varying NC content and stoichiometry currently under investigation to test this assumption as well as to achieve a better understanding of the NC polymer network. In addition, the plasticizer effect on the XLD and mechanical properties will be studied, that is, the plasticizer concentration will be varied in PEG (N100/CW4000 and N100/CW6000) and PGA (NC/HDI in R18 and S1011) systems (Table II) to achieve a better understanding of the interaction between polymer and plasticizer in terms of the XLD and mechanical properties.

A series of gumstocks with a single kind of solid loading will be prepared (Table III) to evaluate the effect of solids on the degree of curing and on mechanical properties; types of solids to be used will include HMX, Al (aluminum), AP (ammonium perchlorate), inert salts and/or glass beads. Three types of particle sizes (e.g., 5μ, 40μ, and 100μ) and various solid loadings (i.e., 10%, 30%, 50%, 55%, 60%, 70%, and 75% for each solid) in combination with two typical binder systems will be investigated. The understanding of the structure/property relationships of gumstocks without fillers has been increased to a great extent of the previous year's study of this continuing program. The study of gumstocks with solids should lead to a much better understanding of the mechanical properties of XLDB propellants.

FUTURE WORK

During the next report period, propellant binders will be manufactured with varying plasticizer content in PEG (N100/CW4000 and N100/CW6000) and PGA (NC/HDI in R18 and S1011) systems to study the effect of the combination of varying NC content and stoichiometry on the mechanical properties and XLD of binders.

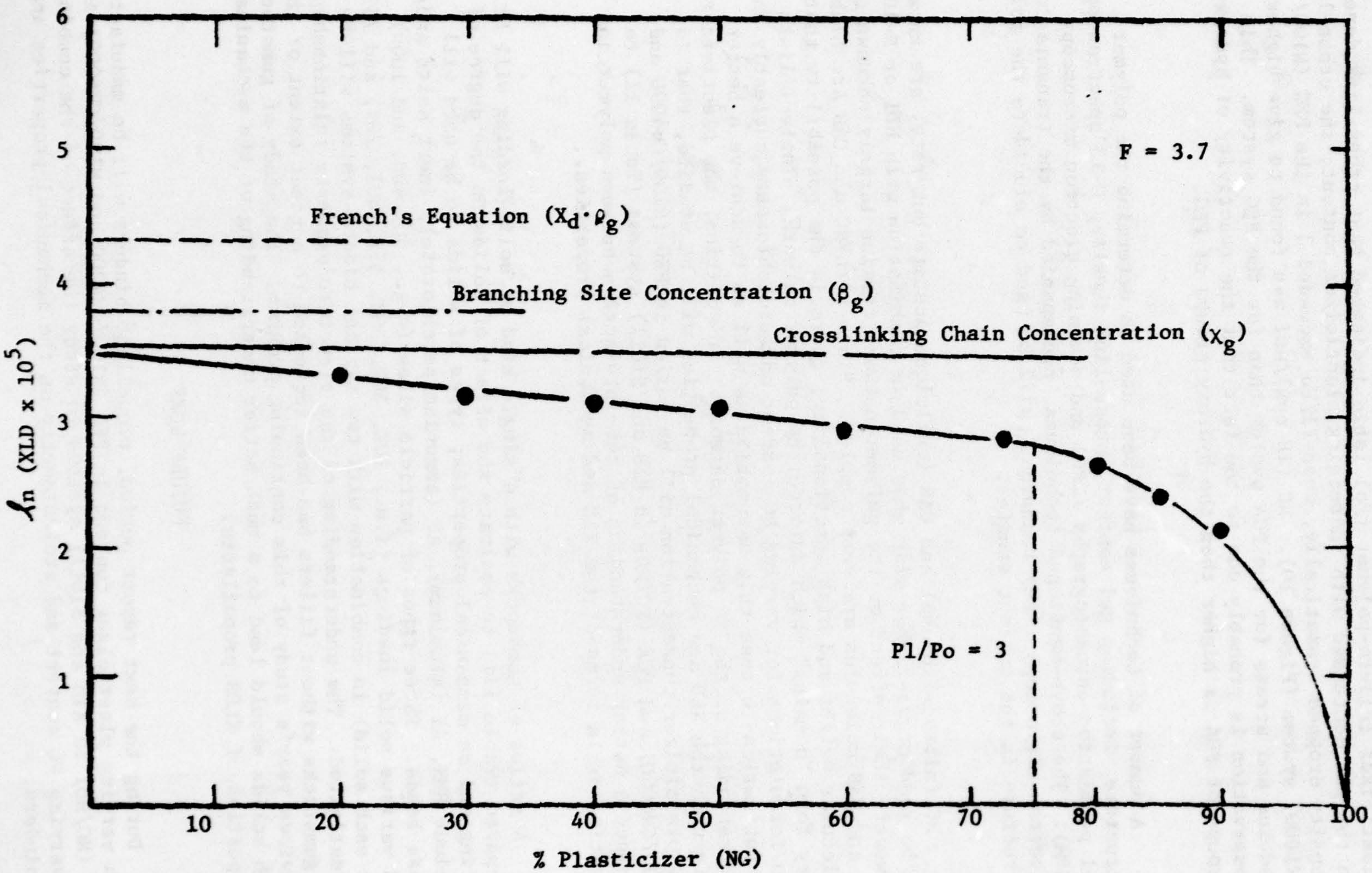


Figure 10. Effect of Plasticizer Content on Cross-Link Density (XLD, for the PEG (N100/CW1000)) System

TABLE I

FORMULATIONS FOR STUDYING THE EFFECT OF VARYING NC (18 cps) CONTENT AND STOICHIOMETRY

NC/PGA:	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	0.95	1.0
NCO/OH										
1.1	X	X	X							
1.0	X	X	X							
0.9	X	X	X	X	X	X	X	X		
0.8	X	X	X	X	X	X	X	X	X	X
0.7	X	X	X	X	X	X	X	X	X	X
0.6				X	X	X	X	X	X	X
0.5				X	X	X	X	X	X	X
0.4						X	X	X	X	X

TABLE II

FORMULATIONS FOR VARYING PLASTICIZER CONCENTRATION IN PEG AND PGA SYSTEMS

Composition:	PEG		PGA	
	N100/CW4000	N100/CW6000	R18	S1011
% Plasticizer				
30	X	-	-	-
40	X	X	X	X
50	X	X	X	X
60	X	X	X	X
70	X	X	X	X
80	X	X	X	X
85	X	X	X	X
90	X	X	X	X

TABLE III

FORMULATIONS FOR STUDYING GUMSTOCKS WITH SOLIDS*

% Solids:	10	30	50	55	60	70	75
Particle Size							
5μ	X	X	X	X	X		
40μ	X	X	X	X	X		
100μ	X	X	X	X	X		
5μ + 40μ (50:50)		X	X		X	X	X
5μ + 100μ (50:50)		X	X		X	X	X
40μ + 100μ (50:50)		X	X		X	X	X

*Solids such as HMX, AP, Al will be studied.